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Compromising postural balance in the elderly

Swanenburg, Jaap ; de Bruin, Eling D ; Uebelhart, Daniel ; Mulder, Theo

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Compromising Postural Balance in the Elderly

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Key Words
Articulation · Attention · Cognition · Dual tasking · Postural balance

Abstract
Background: Additional tasks that are assumed to disturb standing postural control can be divided in added motor or added cognitive tasks. It is unknown which type of task causes the most disturbances of postural control in elderly. ***Objective:*** The aim of this study was to determine whether the dual tasking disturbance of postural control in elderly is caused by vocal articulation or by limited attentional resources. ***Methods:*** 39 elderly (81 ± 7 years) were tested on a force plate in a two-legged standing position. Seven balance variables were assessed: maximum displacement and standard deviation amplitude in the medial-lateral (ML, SDML) and anterior-posterior (AP, SDAP) direction, average speed of displacement (V) and the area of the 95th percentile ellipse (AoE) and sway path (PL) per given time. The following task combinations were tested: no secondary task, repeating a number aloud (articulation), counting backwards aloud (articulation and attention), and counting backwards silently (attention). All tasks were tested with and without vision. ***Results:*** A factorial ANOVA revealed main effects of additional tasks in PL, ML, SDML, AP, AoE and V. Bonferroni post-hoc analysis in a vision situation showed significant difference between no task and counting backwards aloud task in balance variables ML ($p = 0.006$), SDML ($p = 0.002$), AP ($p = 0.020$) and V ($p = 0.003$), respectively. All no-vision situations showed no significant difference between the different tasks. ***Conclusion:*** The findings suggest that the combined articulation and attention-demanding secondary task stressed the attentional system of elderly to such an extent that it compromised the performance of the primary task (quiet standing). The counting backwards aloud task may be used as dual task for clinical balance assessment in at-risk populations. This task was best able to disturb postural control.

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Introduction

Maintaining postural stability requires sensory processes and attentional resources [1, 2]. With increasing age problems emerge in the fast allocation of sensory processes and attentional resources for the maintenance of postural stability. Postural control seems to be more at-

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tention demanding in older adults. It is for this reason that attention-demanding tasks that have to be performed simultaneously with a balance task show deleterious effects on postural control in older adults [3].

Age differences in dual-task performance have been studied by Shumway-Cook et al. [4] who showed that postural balance is disturbed by an additional cognitive task in elderly fallers, whereas young adults showed no such disturbances. Obviously, aging is associated with increased costs of dual-task performance. The added task in postural control investigations can be characterized as cognitive, combined cognitive-motor, or as motor task [3]. Dual-task methodology has been used to assess the coordination of resource allocation to competing tasks [5], and might enable researchers and clinicians to distinguish the level of functional reorganization of a motor system that is reflected in the increasing compensatory costs across time [6].

Counting backwards during postural assessment is often used as an additional attention-demanding task. Counting backwards caused significant degradation of postural stability in both healthy younger and older adults [7–9]. Lezak [10] suggests that counting backwards requires, besides an intact mental arithmetic ability, extensive attention resources.

Yardley et al. [11] tested in young healthy volunteers whether the observed disturbances in postural control were caused by the cognitive aspects of counting backwards or by the vocal articulation of the counting. They investigated the assumption that the observable disturbances might be caused by the motor act of articulation and concluded that the observed increase in the postural sway path was most probably caused by the perturbing effects of articulation and not by the competing demands for attention. Similar results were found in a study by Dault et al. [12] where young volunteers had to listen to spoken letters in order to create words out of these letters. Only in those cases where articulation was involved the sway path of participants increased. A previous study that addressed the question of disturbing effects of motor versus cognitive tasks on age-related postural balance using a dual-task methodology, e.g. a static motor task combined with mathematical calculations, reported that the ability to share attentional resources among different tasks were similar in healthy young and elderly subjects [13].

These findings lead us to several interesting questions: Do the findings of Yardley et al. [11] generalize to older subjects? Which specific aspect of an additional task that contains both cognitive and articulation motor task elements has the most disturbing effect on postural control in elderly? The aim of the present study, therefore, was to investigate whether disturbances in postural control under dual-task conditions in elderly are caused mainly by the additional motor effect of articulation (speaking aloud), mainly by the effect of the additional cognitive component of a task, or mainly by the combination of these two elements. Furthermore, it was investigated whether differences exist between fallers and non-fallers in terms of disturbance of postural control under different additional tasks.

Methods

Participants

Initially, a sample of 40 older people, either living in the community or in a residential care facility, was recruited for the study. The community-dwelling elderly were volunteers from the outpatient department of the Institute of Physical Medicine of the Department of Rheumatology, University Hospital Zurich. Additional participants were recruited by means of a letter containing information about the study with the help of the head of a nearby residential care facility.

The inclusion criteria were: participants of both genders older than 60 years. Exclusion criteria were: unable to understand (language) the purpose of the study, diagnosed as having psychological or psychiatric problems interfering with the aim of the study, suffering from known chronic substance abuse (such as medication or alcohol), and/or being under therapy with neuroleptics, sedatives, anti-epileptics and anti-depressives. All participants gave their written informed consent and were blinded to the purpose of the measurements. The study has been approved by the local ethics committee.

Experimental Protocol

The participant took a comfortable barefooted, double-legged stance on the stable surface of the force platform (AMTI Accusway; Advanced Mechanical Technology, Inc., Watertown, Mass., USA). The force platform measures ground reacting force and moments in 3 orthogonal directions with a sampling frequency of 50 Hz. These provide the centre of pressure (COP) coordinates, which allow calculation of the maximum displacement in the anterior-posterior and medial-lateral direction (AP; ML), root-mean-square amplitude in the anterior-posterior and medial-lateral direction (SDAP; SDML), average speed of displacement (V), the area of the 95th percentile ellipse (AoE), and the sway path per given time (PL).

Because a change in the base of support (BOS) has a substantial effect on postural control [14], the outlines of both feet were marked with tape in order to obtain standardized foot positions across the successive measurements. Maximal BOS width and hip width were measured at the major trochanter femoris, with an anthropometric caliper (Lafayette Instrument Company, Lafayette, Ind., USA). The participants were asked to stand quietly with their arms aside and eyes open while looking straight ahead.

Secondary Tasks

Four different tasks were employed: standing quietly with no secondary task (CONT); standing quietly and repeating a number aloud task (ART); standing quietly and counting backwards aloud task (ART-ATT); standing quietly and counting backwards silently task (ATT). For the standing quietly only task, participants were instructed to stand as still as they could on the platform.

All participants were tested on their counting performance in a sitting position before the actual testing took place. The amount of mistakes made in sitting position was registered for all participants. During the counting backwards task, both aloud and silent, the participant was asked to count backwards in steps of 7 s as fast and accurately as possible during 20 s [10, 15]. Because postural sway varies with the difficulty of a concurrent cognitive task [16], counting backwards was allowed to be performed in different modes. This under the assumption that the attentional demands of the cognitive task thus would be comparable for the study participants and would establish a maximal individual difficulty level. If counting backwards in steps of 7 s was too difficult, steps of 3 s or 1 s were used for the test condition instead. The starting number was selected at random from a range of 80–99. For those participants who could count back from 99 to 0 within 20 s while sitting, a test starting number was selected within a range between 121 and 199. In the repeating a number aloud task, the participant was asked to repeat a two-digit number. Repeating two-digit numbers results in using similar phonological words as compared to the counting backwards aloud tasks [17]; however, it is not attention demanding [11]. Both the counting backwards aloud and silent tasks were continuously controlled for accuracy and every mistake was noted. This was done for the counting backwards silent tasks by selecting the starting number at random from a range of 80–99. After 20 s measurement, the participants had to speak the final number they had counted down to out loud. For the counting backwards aloud tasks this was achieved through verbalizing of the final number after the 20 s. This number was controlled by the measurement assistant. With help of a subtraction list (starting number down to 0) of each possible starting number (80–99) the final number was checked. No feedback on performance was given during the testing.

Vision

Because a reduction in stability without vision occurs in aging, performance was assessed in both vision and no-vision conditions [13, 18, 19].

All tasks were tested under 2 different visual situations:

(a) Normal vision. In this test situation participants were told to focus on a fixed grey cross (1 × 0.5 m) in the middle of a screen (1.5 × 1.5 m) positioned 2 m in front of the forceplate. The center of the grey cross was positioned 1.5 m high. All participants used their own glasses when needed, for optimal visual acuity.

(b) Occluded vision. Vision was occluded with a pair of custom-made opaque goggles that prevented the picking-up of normal visual information (translucent milky texture) but allowed the influx of light. The participants were instructed to keep their eyes open inside the goggles.

Procedures

The participants were tested within a single assessment session that lasted about 45 min. At the start of the session every participant first performed the secondary tasks while seated.

Table 1. Baseline characteristics of the participants

	Community dwellers (n = 14)	Residential stetting (n = 25)	All (n = 39)
Female	13	19	32
Male	1	6	7
Age, years	77 ± 7	83 ± 6	81 ± 7
Range	62/88	70/95	62/95
Weight, kg	66 ± 14	66 ± 11	66 ± 12
Length, cm	163 ± 9	163 ± 8	163 ± 8
Non-fallers	8	14	22
One-time fallers	2	4	6
Multiple fallers (>1 fall)	4	7	11
Mental task			
Serial 7 s	12	21	33
Serial 3 s	2	4	6
Numbers of mistakes			
Total mistakes	3.1 ± 3.3*	3.4 ± 2.9*	3.3 ± 3.1*
Total mistakes during no vision	2.5 ± 2.4*	2.3 ± 2.3*	2.5 ± 2.3*

* Total mental mistakes represent mean numbers of mistakes.

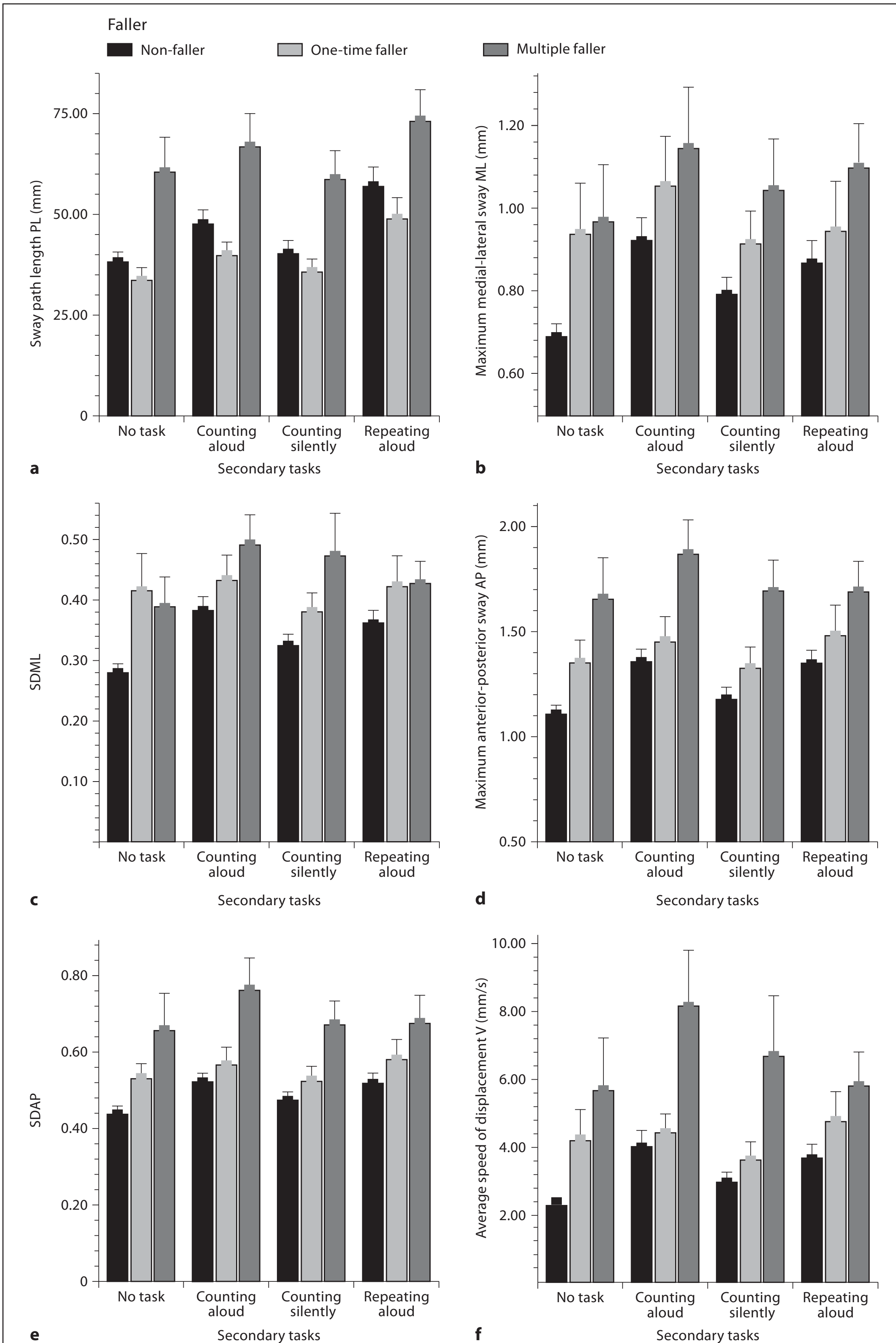
Thereafter, the four tasks (CONT, ART, ART-ATT, ATT) were employed while the participants were standing (postural task). The recording of the postural sway started together with the start of the secondary task. Each task was measured 4 times. Every measurement lasted 20 s followed by a break of 20 s [20]. Between each task, the participants had a 2-min break in which they were allowed to sit on a chair. The measurements took place in random order (task and vision) in order to control for the effects of fatigue and learning.

Falls Assessment

The number of falls in the previous year was assessed by means of an interview. A fall was defined as unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, or sudden onset of paralysis as in stroke or epileptic seizure [21]. Three groups were defined as non-fallers, one-time fallers and multiple fallers.

Statistical Analysis

Descriptive statistics was used to describe participants' demographics. The 4 measurements of each task were averaged to obtain a reliable measure [22]. The one-sample Kolmogorov-Smirnov test was used to check the normality of the resulting distributions. In case of non-normal distribution, a log transform was performed. Because the assumptions for a multivariate approach were not met, univariate analyses were executed. A 4 (secondary tasks) × 3 (fall status) × 2 (vision/no-vision) fractional ANOVA was conducted to examine main and interaction effects. Post-hoc analyses were conducted to evaluate the influence of each secondary task and faller's group allocation under both vision situations



Faller
Non-faller
One-time faller
Multiple faller
Sway path length PL (mm)
75.00
50.00
25.00
0
No task
Counting aloud
Counting silently
Repeating aloud
a
Secondary tasks
Maximum medial-lateral sway ML (mm)
1.20
1.00
0.80
0.60
b
SDML
0.50
0.40
0.30
0.20
0.10
c
Maximum anterior-posterior sway AP (mm)
2.00
1.50
1.00
0.50
d
SDAP
0.80
0.60
0.40
0.20
e
Average speed of displacement V (mm/s)
10.00
8.00
6.00
4.00
2.00
f

Table 2. Main effects of the fractional ANOVA

	Secondary tasks			Fallers			Vision		
	F (3/288)	p	OP	F (2/288)	p	OP	F (1/288)	p	OP
ML	2.696	0.046*	0.65	9.336	<0.000	0.98	5.225	0.023*	0.63
SDML	2.674	0.048*	0.65	11.427	<0.000	0.99	2.555	0.111	0.36
AP	2.684	0.047*	0.65	26.794	<0.000	1.00	8.956	0.003*	0.85
SDAP	1.967	0.119	0.51	21.996	<0.000	1.00	4.850	0.028*	0.59
AoE	2.815	0.040*	0.67	25.073	<0.000	1.00	11.823	0.001*	0.93
V	3.294	0.021*	0.75	17.691	<0.000	1.00	5.799	0.017*	0.67
PL	5.184	0.002*	0.92	30.101	<0.000	0.99	9.508	0.003*	0.85

F = F value; p = p value; OP = observed power. * Significant p < 0.05.

when a main effect was found to be significant. In order to reduce the chance of a type I error, the more conservative Bonferroni and the Tamhane T2 post-hoc tests were used. The data were entered, stored, and analyzed in SPSS 12.0.1 statistical software (SPSS, Inc., Chicago, Ill., USA).

Results

Of the 40 participants who started the measurement, one participant abandoned the measurements of his own will. The remaining 39 participants had an average age of 81 ± 7 years (range 62–95 years). 33 participants were able to count backwards in 7 s and 6 participants in 3 s. The characteristics of all participants, including the mistakes made on the secondary tasks, are summarized in table 1. Three of four mistakes were made during the no-vision condition. There were 22 non-fallers, 6 one-time fallers and 11 multiple fallers. The means of all postural balance variables showing significant differences between the secondary conditions, partitioned in non-fallers, one-time fallers and multiple fallers, are presented in figure 1a–f.

Fig. 1. a Sway path length (PL) per 20 s with vision. **b** Maximum displacement in the medial-lateral direction (ML) with vision. **c** Root-mean-square amplitude in the medial-lateral direction (SDML) with vision. **d** Maximum displacement in the anterior-posterior direction (AP) with vision. **e** Root-mean-square amplitude in the anterior-posterior direction (SDAP) with vision. **f** Average speed of displacement (V) with vision. Error bars show mean ± 1.0 SE; bars show means.

Because of non-normal distribution, all balance variables were log transformed for data analysis.

The factorial ANOVA revealed main significant effects of secondary tasks in ML ($F(3/288) = 2.696$, $p = 0.046$), SDML ($F(3/288) = 2.674$, $p = 0.048$), AP ($F(3/288) = 2.684$, $p = 0.047$), AoE ($F(3/288) = 2.815$, $p = 0.040$), V ($F(3/288) = 3.294$, $p = 0.021$) and PL ($F(3/288) = 5.184$, $p = 0.002$).

Main effects between the non-fallers, one-time fallers and multiple fallers were found in all balance variables; ML ($F(2/288) = 9.336$, $p < 0.001$), SDML ($F(2/288) = 11.427$, $p < 0.001$), AP ($F(2/288) = 26.794$, $p < 0.001$), SDAP ($F(2/288) = 21.996$, $p < 0.001$), AoE ($F(2/288) = 25.073$, $p < 0.001$), V ($F(2/288) = 17.691$, $p < 0.001$) and PL ($F(2/288) = 30.101$, $p < 0.001$).

Because of unequal sample size a Tamhane T2 post-hoc analysis was used to analyze the differences between non-fallers, one-time fallers and multiple fallers. Significant differences between non-fallers and multiple fallers were found for all balance variables, for both the vision and no-vision test situations (table 4). Non-fallers and one-time fallers differed significantly only in no-vision test situations in ML ($p = 0.034$) and SDML ($p = 0.014$) and V ($p = 0.018$). Multiple fallers and one-time fallers showed a significant difference in both vision and no-vision test situations in variable AoE ($p < 0.001$) and PL ($p < 0.001$). The results are summarized in table 4.

The vision test situation revealed a main effect in most balance variables; ML ($F(1/288) = 5.225$, $p = 0.023$), AP ($F(1/288) = 8.956$, $p = 0.003$), SDAP ($F(1/288) = 4.850$, $p = 0.028$), AoE ($F(1/288) = 11.823$, $p = 0.001$), V ($F(1/288) = 5.799$, $p = 0.017$) and PL ($F(1/288) = 9.508$, $p = 0.003$). The results of the factorial ANOVA are summarized in table 2.

Table 3. Follow-up analysis between the different tasks

	CONT/ART-ATT		CONT/ATT		CONT/ART		ART/ATT	
	vision	no-vision	vision	no-vision	vision	no-vision	vision	no-vision
ML	0.006*	0.558	0.566	1.000	1.000	0.065	0.072	0.347
SDML	0.002*	0.686	0.256	1.000	0.203	0.802	1.000	1.000
AP	0.020*	0.851	0.778	1.000	0.192	1.000	1.000	0.759
SDAP	0.041*	1.000	0.392	1.000	0.540	1.000	1.000	0.462
AoE	0.139	0.798	1.000	1.000	0.106	0.560	0.661	1.000
V	0.003*	0.474	0.278	1.000	0.132	0.455	1.000	0.708
PL	0.158	1.000	1.000	1.000	<0.000*	0.445	0.001*	0.477

CONT = No additional task; ART-ATT = counting backwards aloud; ATT = counting backwards silent; ART = repeat a number aloud. * Significant p < 0.05.

Table 4. Follow-up analysis between the non-fallers and multiple fallers, non-fallers and one-time fallers and multiple fallers and one-time fallers in both vision situations

	Non-fallers/multiple fallers		Non-fallers/one-time fallers		Multiple fallers/one-time fallers	
	vision	no-vision	vision	no-vision	vision	no-vision
ML	0.042*	0.016*	0.811	0.034*	0.578	1.000
SDML	0.033*	0.012*	0.235	0.014*	0.766	0.985
AP	<0.000*	<0.000*	0.121	0.054	0.122	0.237
SDAP	0.001*	0.001*	0.089	0.102	0.295	0.113
AoE	<0.000*	0.002*	0.769	0.522	<0.000*	<0.000*
V	0.005*	0.001*	0.087	0.018*	0.473	0.738
PL	<0.000*	0.003*	0.950	0.419	<0.000*	<0.000*

* Significant p < 0.05.

Secondary Tasks

One-way ANOVA with Bonferroni post-hoc analysis in the vision situation showed significant differences between CONT and ART-ATT in ML ($p = 0.006$), SDML ($p = 0.002$), AP ($p = 0.020$) and V ($p = 0.003$), respectively.

Significant differences in PL were found between the CONT and ART task ($p < 0.001$) and the ART and ATT task ($p = 0.001$).

All test sessions under the no-vision situation showed no differences in postural balance measures between the tasks. The results are summarized in table 3. Follow-up analysis between the non-fallers and multiple fallers, non-fallers and one-time fallers and multiple fallers and one-time fallers in both vision situations are summarized in table 4.

Discussion

The main aim of the present study was to investigate whether the observed disturbances in postural control under dual-task conditions in the elderly can be attributed to cognitive, cognitive-motor or to motor effects. Our results showed that the disturbing effects on postural control caused by the counting backwards aloud task that was used as an example of a combined motor and attention-demanding task, were significantly larger than the disturbing effect caused by the sole motor aspect of articulation. This finding contrasts clearly with previous research where a similar test protocol was used in a younger population [11, 12]. The latter study showed that the main cause for postural disturbance was attributable to the additional motor task only. The main difference between the results of the present study and that of Yardley et al. [11] seems to be that older adults' balance was only affected by the combined motor-plus-cognitive task condition while Yardley et al. [11] showed that younger adults' balance was affected by both the motor-alone and the motor-plus-cognitive task conditions. The results of the present study may suggest that neither attentional nor articulatory processes alone may be the main influence factor for older adults' disturbances in postural control – in contrast to younger adults, where articulatory processes alone seem to play the main role. Hence, in the present study, it was not the motor effect of articulation that disturbed postural control, but the simultaneous performance of the attention-demanding tasks and the motor effect of articulation. This finding has clear clinical relevance for the design of postural balance test protocols for the elderly where the emphasis should be put on additional attention-demanding tasks in combination with articulation.

Weeks et al. [13] previously addressed the question of disturbing effects of motor versus cognitive tasks on age-related postural balance using a dual-task methodology. The authors reported that the ability to share attentional resources among focal and postural tasks were similar in healthy young and elderly subjects. This finding seems to contradict the findings of our study. In our opinion, there are, however, two possible reasons that might explain the observed differences. The first difference between the study protocol that Weeks et al. [13] used and our protocol was that we expected our subjects to perform a dynamic motor task (articulation), whereas Weeks et al. [13] used a static motor task (a bilateral finger-thumb static pinch task). It can be expected that a dynamic task challenges postural control more since it influences the body center of mass. The second important difference is that the subjects of Weeks et al. [13] were wearing a pair of small force transducers (one for each hand) consisting of a U-shaped aluminum, together with rubber gloves. In analogy to the principle that tightrope walkers use by wearing a weight below their body center of mass, it can be expected that the additional weight in the hands with the arms hanging at the side of the subjects lowers the body center of mass and, therefore, increases postural stability. These two factors combined with the fact that the study population of Weeks et al. [13] was somewhat younger might explain the observed difference in outcome [13].

It was remarkable that dual tasking in the no-vision situation caused no additional disturbances in postural control. Postural balance decreases when vision is removed [23, 24]. What could be observed in our study, however, was a deterioration of the performance of the cognitive task in the no-vision conditions. Three out of four mistakes were made during the no-vision condition. It seems that in a no-vision dual-task situation, both postural control and counting were affected. This can be explained by a competition for resources that is taking place. This resource competition refers to concurrent tasks that interfere with each other and, hence, challenge the capacity-limited pool of resources [3]. This might explain why the participants did not show any extra decrease in postural balance, but deteriorated in their performance of counting which would indicate that postural balance was prioritized. A similar phenomenon was described by Lundin-Olson et al. [25] for walking. With the phrase 'stops walking while talking' they were describing that institutionalized older adults were often unable to continue walking while talking at the same time. Individuals that were unable to perform these tasks simultaneously had a significantly increased risk of falling in the next 6 months. It can be speculated that a similar phenomenon took place in the individuals of this study. At the very least it seems fair to say that the different effects caused under dual tasking in a no-vision situation should be subject to further study.

The significant differences that were obtained between multiple fallers and non-fallers in the dual-task testing conditions showed that force-plate measurements may form a relevant procedure for the objective assessment of fall risk in the elderly. This finding is in accordance with the results of a recent review that suggested that certain aspects of force platform measurements may, indeed, have predictive value for subsequent falls [26]. However, until now only a few prospective studies exist that have used the force platform technique to predict future falls. Thus, some caution remains necessary until prospective studies confirm our assumption in a large sample.

Another aspect of this study that has to be viewed with some caution is the results that relate to the significant differences between fallers and non-fallers that we observed. Because our measurements were taken after the fall events took place it may be that balance changes were caused, at least in part, by secondary (psychological) effects of the fall. But, if that would be the case, these effects would have influenced the data of all conditions.

Judging from the figures on the different postural balance indicators, one may come to the conclusion that the no-secondary task condition may already be able to differentiate well between non-fallers and multiple fallers.

We had reason, however, to not follow-up on this finding. As stated in the introduction, it can be assumed that single-task methodology will be less optimal in clinical settings since it can mask real changes. This means, that single tasking per se will have lesser meaning in clinical settings and should always be complemented by dual tasking [5, 6].

In conclusion, our findings showed that a combined articulation and attention-demanding secondary task stressed the attentional system of elderly most, which resulted in lesser postural control. The use of such a task compromised the performance of the primary standing task. The counting backward aloud task had the most disturbing influence on balance variables. This additional task may, therefore, be most appropriate to be used as an 'attentional probe' for clinical balance assessment. Multiple fallers and non-fallers could be distinguished based on their postural balance values. Prospective research should address the issues of fall prediction with our protocol.

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